Progress in Design and Construction of the Optical Communications Laser Laboratory

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ABSTRACT

The deployment of advanced hyperspectral imaging and other Earth sensing instruments on board Earth observing satellites is driving the demand for high-data-rate communications. Optical communications meet the required data rates with small, low-mass, and low-power communications packages. JPL, as NASA's lead center in optical communications, plans to construct a 1-m Optical Communications Telescope Laboratory (OCTL) at its Table Mountain Facility (TMF) complex in the San Gabriel Mountains of Southern California. The design of the building has been completed, and the construction contractor has been selected. Ground breaking is expected to start at the beginning of the 1999 TMF construction season. A request for proposal (RFP) has been issued for the procurement of the telescope system. Prior to letting the RFP we conducted a request for information with industry for the telescope system. Several vendors responded favorably and provided information on key elements of the proposed design. These inputs were considered in developing the final requirements in the RFP.

Keywords: Free space optical communications, lasercom, telescopes, ground stations, adaptive optics, astrometry, Table Mountain Facility

1.0 INTRODUCTION

The successful bidirectional space-to-ground optical communications demonstrations conducted with the ETS-VI spacecraft[1,2] will be followed by a series of turn-of-the-century space-to-space and space–to ground demonstrations at data rates ranging from 2 Mbps to 2.5 Gbps[3,4,5,6] . To support its future optical communications demonstrations, NASA is building a 1-m Optical Communications Telescope Laboratory (OCTL) transceiver station at its Table Mountain Facility complex in the San Gabriel Mountains of Southern California[7]. Although it is designed as a multipurpose telescope, the OCTL's principal function is to support NASA's optical communications technology development and demonstrations. Consequently, the key requirements of the station are to:

- Conduct communication experiments and demonstrations with laser-bearing spacecraft from low earth orbit (LEO) to deep space, with emphasis on deep space telemetry.
- Develop optical spacecraft communications technologies, with emphasis on deep space applications, by conducting ground-to-ground, ground-to-LEO, and ground-to-deep space experiments.

The OCTL will support optical communications technology areas to include:

- Development of procedures and technologies to enable establishment of handshaking between the spacecraft(S/C) and the ground optical station for initiation of downlink.
- Development of procedures for tracking of deep space missions by optical telescopes.
- Development of back-end electronics systems for reception of downlink from deep space probes.

- Characterization of day-sky and night-sky background under various atmospheric conditions at wavelengths of interest to deep space communications. This will help in the prediction and design of robust optical communications links.
- Day/night field evaluation of optical components (filters, detectors, etc.) that are critical to optical communications. For example, the characterization of the performance of new narrow band filters, to test transmit/receive isolation, and the development of techniques such as adaptive optics to narrow the field of view and suppress background light levels.
- Characterization of end-to-end space/ground communication links with emphasis on deep space telemetry.
- Evaluating coding and protocols for robust optical communications applicable to deep space links.

The building contract has been let to Dumarc Corp., and building construction is scheduled to start in the spring of 1999, with completion by the end of September 1999. The RFP for the telescope has been let, and we expect to award the contract by April of 1999. In this paper we describe the developments in the OCTL specification and procurement process that have transpired over the past year. The key OCTL design requirements for optical communications are described in Section 2. In Section 3 we describe the criteria and process for selecting the building location on the TMF grounds, and the results of thermal measurements that dictated the choice of ground cover to surround the building. The results of soil boring measurements for pier support are also briefly described in this section. The summary is given in Section 4.

2.0 OCTL DESIGN REQUIREMENTS

The OCTL is designed to support daytime and nighttime optical communications demonstrations with laser bearing satellites from LEO to deep-space ranges. These top-level design requirements flowed down as the following requirements to the key subsystems:

Tracking

- Telescope must track with less than 10 microradians line-of-sight RMS jitter at frequencies below 20 Hz.
- Telescope control software must operate with Tracking and Data Relay satellite, North American Aerospace Defense Command, Global Positioning Satellite and JPL deep space predicts.

Optical Train

- Primary mirror is 1-m, excluding turned edge, and is coated with a protected high-reflectance metal coating.
- Reflectance of mirrors M2 through M7 must be comparable to that of Denton FSS-99 in the near-IR wavelength range.
- All optical surfaces must be of high optical quality to support future adaptive optics work.
- Mirror coatings must withstand >10 MW/cm^2 optical power densities.
- Telescope must meet all specified performance requirements when pointed within 30 degrees of the Sun.

A schematic of the OCTL telescope, dome enclosure, coude and Cassegrain foci, and laser lab area are shown in Figure 1. The telescope and its pier are supported by the laser lab foundation. This foundation is in turn anchored by piers into the bedrock, and is vibrationally isolated from the rest of the building. When the dome is open, the telescope and the mirrors in the pier down M7 at the base of the pier are exposed to the outside temperature to minimize the thermal gradients along the optical train. The pier and its mirrors are thermally isolated from the laser lab and light is optically coupled to and from the telescope via a pair of anti-reflection coated and wedged sapphire windows.

The building is maintained at a slight positive pressure to minimize the accumulation of dust on optical surfaces. Motors and fans for air exchange are mounted on vibration-damped platforms on floors vibrationally de-coupled from the building.

3.0 OCTL SITE LOCATION AND SURVEY

The five sites considered for locating the OCTL at TMF are shown in Figure 2. Sites 1 and 2 are close to the main buildings and roadways on the site and afforded ready access to telephone, power and water, and to snow removal services during the winter months. Site 1 afforded a 360° mask down to below 20° elevation with the removal of three trees. Site 2 afforded approximately a 250° mask down to below 20° elevation with the removal of two trees. However, 110° of the 360° field was obscured by building TM-28.

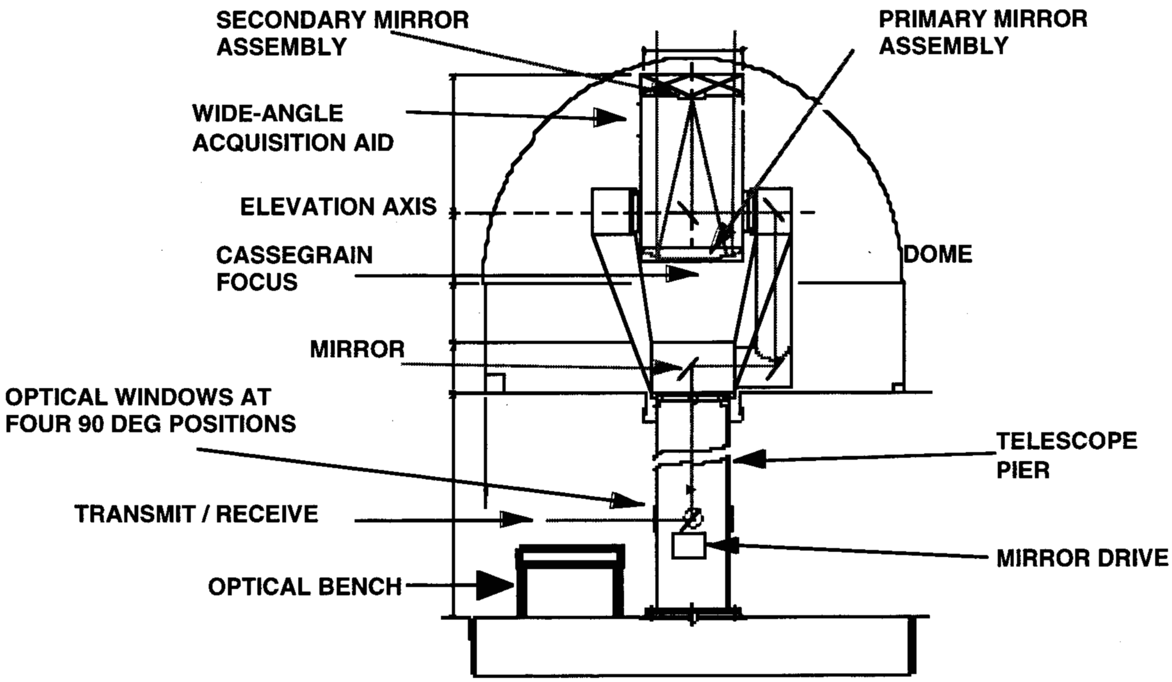

Figure 1: Schematic of the 1-m telescope with acquisition telescope and dome. The coude path mirrors and pier are also shown along with the isolation pad and a laser on an optical bench near coude focus. The Cassegrain focus is also shown.

Sites 3, 4, and 5 were further removed from the main buildings, but close to the main access road. They potentially offered 360° mask down to lower elevations. Sites 3 and 4 offered a 360° mask down to 15° elevation with the removal of 6 and 5 trees, respectively. Site 5 offered a 357° unobstructed view down to below 15° elevation with the removal of only two trees. The 3° loss of field-of view was due to the obscuration by the building TM-2 located approximately 50 m away. Site 5 was located on the only level ground in a steeply graded area. Other sites in this general location were on a steep grade and would have resulted in a significant cost impact to the project.

The site at location 1 was selected since it best satisfied the key criteria. These were: (i) proximity to power, water, and telephone lines on the site, (ii) proximity to regular snow removal paths and (iii) a 360° mask down to below 20 ° elevation with no obscuration from other buildings on the site, and requiring the removal of few trees. The latter criterion was a key concern of the US Forestry Service, with whom we arranged to replace the removed trees at another location on the site.

Results from boring samples taken at location 1 showed that this surface consisted of sands, gravel and silty sands to a depth of 1.5 m to 3 m[8]. This surface material was underlaid by bedrock that was composed of granite and weathered metamorphic bedrock, at least down to the maximum boring depth of 6.6 m.

The San Andreas earthquake fault lies about 1 km to the south-southwest of the selected location. However, a review of geological maps by Kleinfelder, Inc.[8] showed that there were no known earthquake faults traversing or trending towards the site. Thus the probability of surface rupture during a seismic event is considered low. In addition, the groundwater level is below 6.6 m making the potential for liquefaction during a seismic event negligible.

It is well known that the temperature differences between the telescope and the ambient air are the principal cause of degraded seeing in telescopes. To reduce the effects of thermal gradients, the OCTL telescope will be preconditioned so that it will be at the expected ambient temperature at the time of operation. To further reduce the effects of thermal gradients, the grounds around the OCTL building will be covered by asphalt. We measured the thermal lag between the air and the three ground covers: concrete, asphalt and soil. The results show that the thermal lag is least for the soil and greatest for concrete.

Asphalt will provide a stable surface to access the building for heavy equipment deliveries, while minimizing the temperature gradients and associated turbulence around the facility caused by thermal lag between the ground and the ambient air.

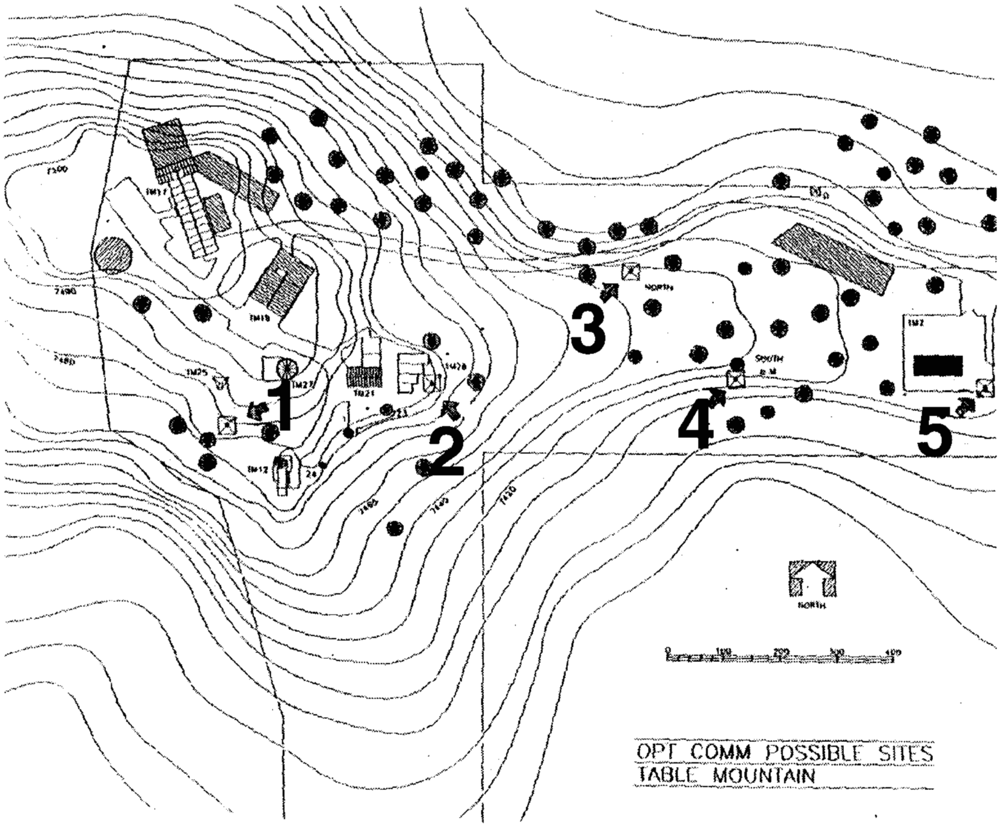

Figure 2: Topographic map of TMF that shows the elevations of the five sites considered for the OCTL. The dark circles represent the locations of pine trees. TM-12 and TM 27 are the transmitter and receiver telescopes, respectively, that were used during the GOLD experiments. The arrows point to the locations discussed in the text.

For the thermal lag measurements, all of the temperature sensors were placed in the same general area at TMF. Thermocouples in the concrete and asphalt surfaces were taped in 2 mm to 5 mm deep holes, and were shaded from direct solar illumination. The thermocouple in the soil was buried approximately 6-mm below the surface. The air thermocouple was located approximately 25 cm above the surface and shaded from direct sunlight. Measurements were taken hourly for a period of 80 hours. During the day the surface temperatures increased up to 8 °C above the air temperature, with a 1° to 2 °C difference between the surfaces. At night the surfaces cooled to 2° to 3 °C below the ambient air, with about a 1°C difference between the surfaces.

4.0 SUMMARY

We have described the progress in the development of the NASA/JPL optical communications telescope laboratory. This laboratory is designed to support the technology development for NASA's optical communications program, including future optical communications demonstrations with spacecraft from LEO to deep space ranges. The laboratory will be built at NASA's TMF site in the San Gabriel Mountains of Southern California near Wrightwood. Building construction is scheduled to begin in the spring of 1999, with completion by September 1999. The contract for the telescope with dome and pier is expected to be let in April of 1999, and first light is expected October 2000.

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